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A PORTABLE CHAMBER FOR RAPID EVAPOTRANSPIRATION MEASUREMENTS ON FIELD PLOTS[1]

D. C. Reicosky and D. B. Peters[2]

ABSTRACT

The increased importance of water-use efficiency in agricultural production has prompted the need for new techniques to measure evapotranspiration (ET) on field plots to evaluate the effects of new soil and water management practices on plant-water use and stress. This note describes the design and performance of an inexpensive, portable chamber for rapid field measurement of ET. This chamber was constructed from aluminum conduit covered with Mylar film and mounted on a farm tractor for portability. The air within the chamber was mixed continuously with four strategically located fans. The ET rate was calculated from the air and wet-bulb temperatures of a thermistor psychrometer before the chamber was lowered on the plot and 1 min later. The psychrometer's accuracy was checked by measuring the transpiration from a solution-absorption system that accurately measured the change in solution level using an LVDT-float system. When microclimatological conditions were changing slowly, transpiration was assumed to be equal to the absorption. The high correlation between measured absorption and transpiration rates indicated reasonable accuracy. The chamber's accuracy and rapidity of the measurement, portability, and relatively low cost makes it a useful tool in measuring ET under field conditions.

Additional index words: **Water uptake, Transpiration, Thermistor psychrometer, Plant-water use.**

PLANT-WATER use is vital in agricultural production and environmental protection. Intensified agriculture requires more efficient use of available water resources. To study plant-water use under different soil and water management practices in the field, development of reliable low-cost equipment is necessary. Musgrave and Moss (1961) and Decker et al. (1962) described portable chambers for measuring photosynthesis and transpiration in the field. More recently, Peters et al. (1974) described an automated traveling system. Our objective in this note is to describe the design and performance of an inexpensive portable chamber for rapidly measuring evapotranspiration (ET) in the field.

METHODS AND MATERIALS

The chamber was constructed of 1.9-cm rigid aluminum conduit, braced across the top and sides, and covered with 0.127-mm thick Mylar[3] film. The dimensions, which were 183 cm long by 203 cm wide by 137 cm high, enabled ET measurement over a 183-cm length of two rows of soybeans (*Glycine max* L. Merr.) spaced 102 cm apart. These dimensions could be easily altered for measuring ET for different crop heights and row spacings; e.g., a 244-cm high chamber was constructed for corn (*Zea mays* L.)

The chamber was mounted on the front frame of a medium-sized farm tractor (Fig. 1) with the power steering essential for precise location of the chamber over the plots. The chamber could be lifted in 8 sec and lowered (230 cm) in 5 sec with a 0.635 cm diam wire cable and a "My-te"[3] model 20-12HC battery-operated winch. Four fans, mounted near the chamber's bottom between the plant rows and directed diagonally upward, were used to circulate the air continuously. Each fan delivered 13.2 m^3/min, recycling the air 9 times/min. Two of the fans were directed toward the thermistor psychrometer mounted near the top center of the chamber to assure a 3 m/sec minimum air velocity.

A thermistor psychrometer, partially shielded from direct radiation with aluminum foil so as to prevent disruption of the airflow, was used to measure the rate of change of water vapor concentration. Yellow Springs Instrument Co. Thermilinear Components[3] (part #44202) were used to provide a 10 mv/C output for both the air temperature and wet-bulb temperature sensors. The wick around the wet-bulb sensor was wetted with distilled water supplied by a gravity-fed system. The outputs of the temperature sensors were fed directly into a 2-pen X-Y recorder, with 0.2% accuracy. The power for the fans and the recorder was supplied by an extension cord, but could easily have been supplied by a stable portable generator or a DC-to-AC tractor-mounted inverter. The cost of the materials in the chamber was about $210.00.

The ET rate was calculated from the rate of change of water vapor concentration, using the ideal gas law and the psychrometric equation as follows (List, 1958):

$$e = e' - 0.00066\,(P)\,(T_a - T_w)\,(1 + 0.00115T_w) \qquad [1]$$

where e is the ambient vapor pressure (mb); e′ is the saturation vapor pressure (mb); P is the atmospheric pressure (assumed = 1,000 mb), and T_a and T_w are the air and wet-bulb temperatures (C), respectively. The ambient vapor pressure, e, is then substituted in the ideal gas equation with the appropriate constants

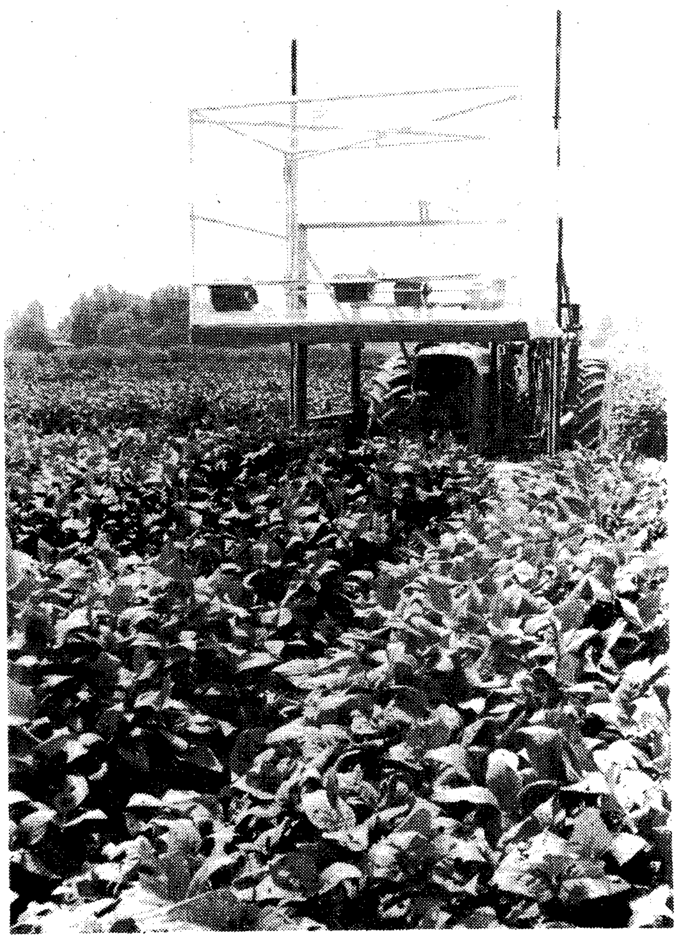

Fig. 1. Evapotranspiration chamber mounted on a farm tractor.

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[2] Soil scientists, Florence, S. C., and Urbana, Ill., respectively.

[3] Trade names are used for identification purposes only and do not imply preference for this item by USDA.

to yield, ρ_v, the density of water vapor (g/m³) as

$$\rho_v = \frac{217\,(e)}{T_K} \qquad [2]$$

where T_K is the Kelvin temperature (T_a + 273.15 C). The initial vapor density, ρ_{vi}, was calculated from T_a and T_w just before placing the chamber over the plot. The final vapor density, ρ_{vf}, was calculated 1 min after the chamber had been placed over the plot. The rate of vapor production in the chamber of volume, V, between the initial time, t_i and final time, t_f, over the soil area, A_s, is then assumed to be the ET rate, ET, as follows:

$$ET = \left(\frac{\rho_{vf} - \rho_{vi}}{t_f - t_i}\right)\left(\frac{V}{A_s}\right) \qquad [3]$$

Calibration

The chamber accuracy was checked by simultaneously measuring the solution-uptake and transpiration rates of soybean plants at various times during the growing season. The plants were grown in standard Hoaglands solution in a solution-uptake tank. Under steady-state microclimatological conditions with the soil surface covered with polyethylene sheets, solution-uptake rate was assumed equal to the transpiration rate.

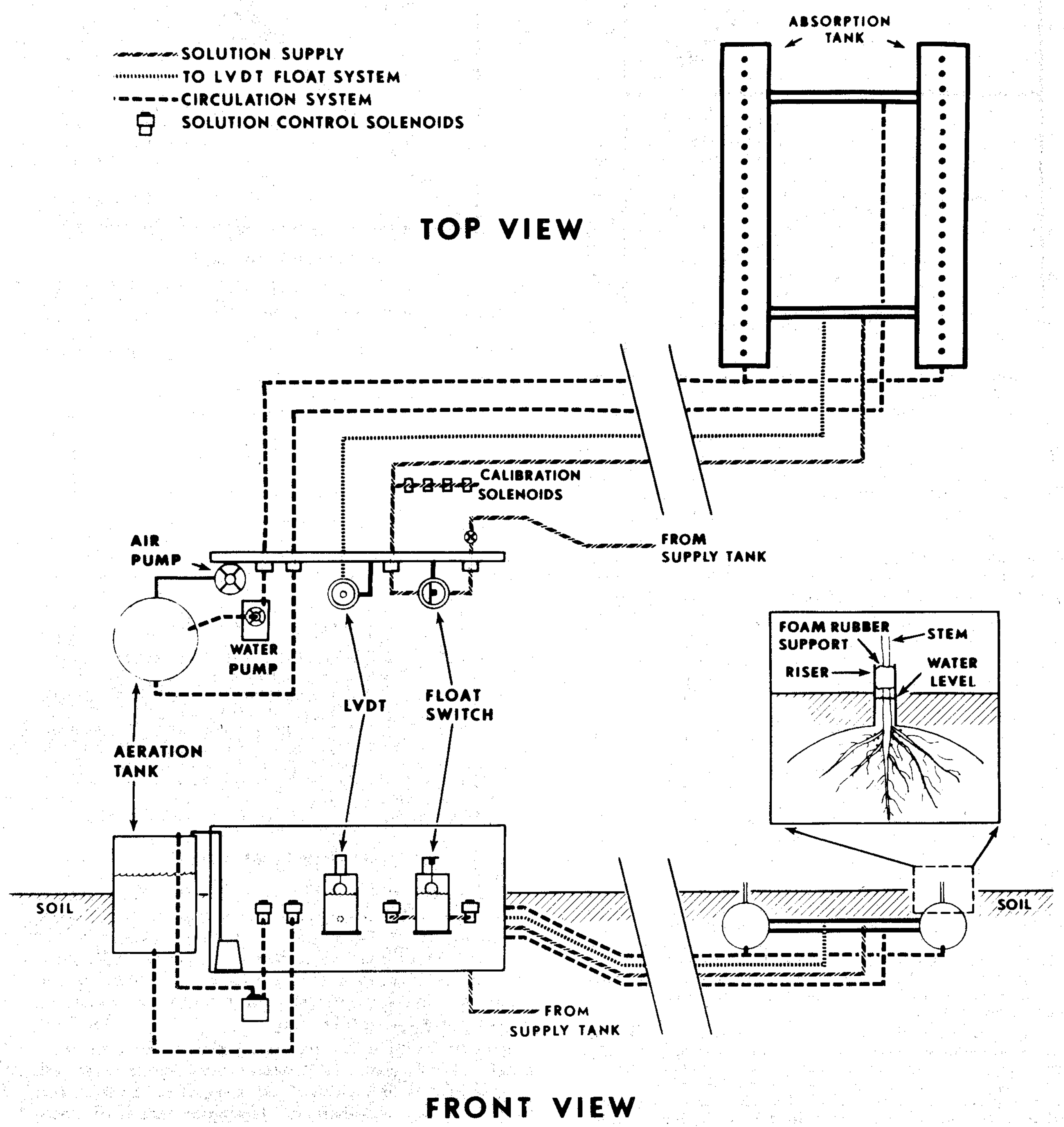

Fig. 2. Schematic representation of solution-absorption system used to check the transpiration measurements.

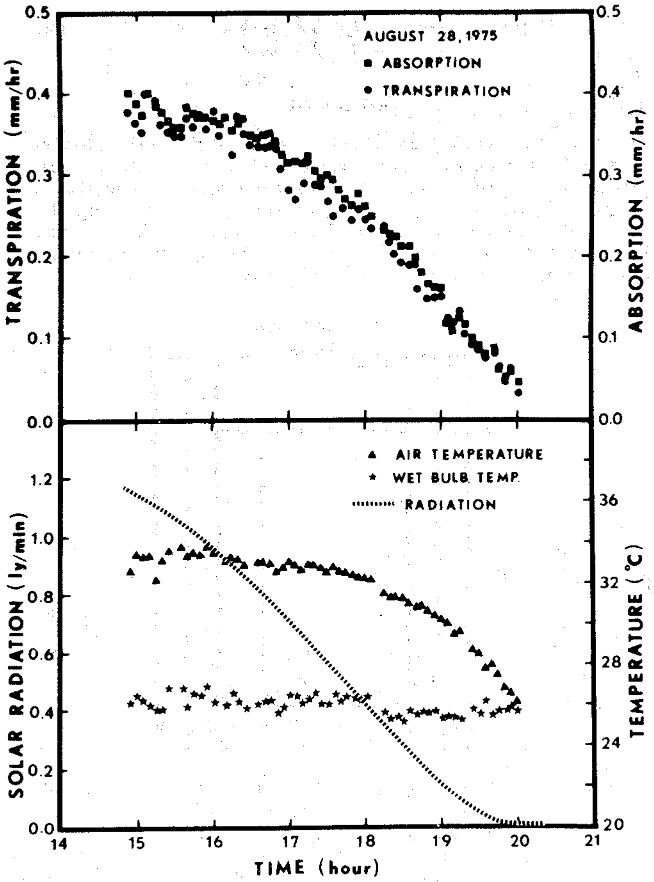

Fig. 3. Summary of solution absorption, transpiration, solar radiation, air and wet-bulb temperatures on 28 August 1975.

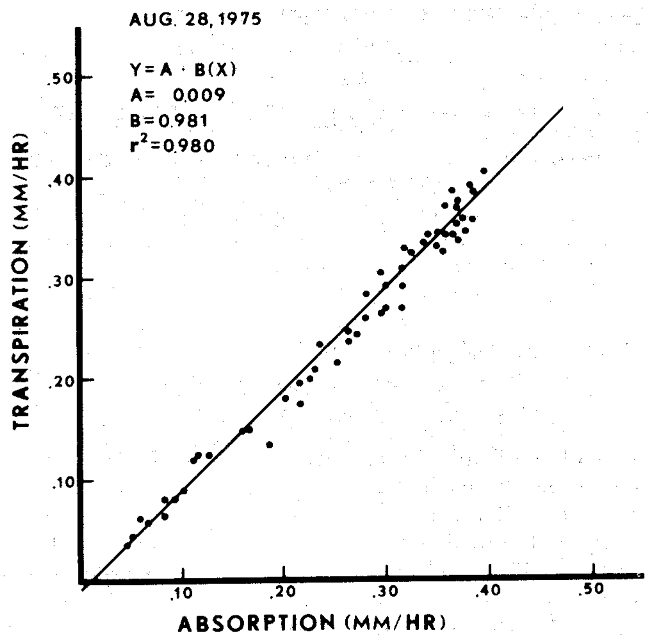

Fig. 4. The relationship between measured transpiration and solution absorption on 28 August 1975.

The solution-uptake tank consisted of two pieces of 25-cm inside diam. (id.) PVC pipe 1.68 m long, spaced 102 cm apart, connected with two sections of 5.1-cm i.d., PVC pipe as shown in Fig. 2. The plant stems were wrapped with polyurethane foam and placed in each riser (1.3-cm i.d., PVC pipe 7 cm high) spaced 7 cm apart. The solution-uptake tank was placed in the soil with the top of the risers about 3 cm above the soil surface. All hydraulic connections with the control panel located about 5 m from the solution-uptake tank. were underground.

The change in solution level was measured using an LVDT-float system described earlier (Phene and Campbell, 1975). The LVDT (Linear Variable Displacement Transducer) used to measure the solution level was a Trans-Tek[3] model 244 DC-DC LVDT with a 24-V input resulting in an output of 11.0 V/cm. Because of the sensitivity of the measuring system to air bubbles, the solution was aerated outside the solution-uptake tank by pumping from the solution-uptake tank into an aeration tank with a condensate pump, and then recirculated back into the solution-uptake tank (Fig. 2).

The level in the solution-uptake tank was controlled by a float switch that operated a normally closed solenoid valve. All solenoids were controlled by a recycling cam timer on a 10-min cycle with 20% of the cycle for measurement. The outputs of the LVDT and an Eppley[3] pyranometer were recorded on a two-pen strip-chart recorder with an accuracy of 0.25% of span. After the measurement cycle ended, the whole system reequilibrated in about 3 min.

As the plant stem diameter increased, periodic recalibration of the solution-uptake system was necessary. During the night, when plant uptake was small, four other calibration solenoid valves sequentially released the solution from the solution-uptake tank at different flow rates. The calibration factor was calculated from the outflow rate determined by collecting the solution in a graduated cylinder and by simultaneously measuring the change in the solution level with the LVDT-float system. The cost of the materials in the solution uptake system was about $460.00 with the LVDT and solenoids the major costs.

Chamber Operation

The operation of the chamber consisted of maneuvering the tractor and placing the chamber over a previously marked plot or over the solution uptake tank. With the chamber in place over the plot or the solution-uptake tank in the raised position with the fans running, the recorder was started to establish that the air temperature (T_a) and the wet-bulb temperature (T_w) were constant (about 1 min).[1] Then the chamber was lowered and the chart marked. The chamber was left over the plot in the down position for exactly 1 min at which time the final air and wet-bulb temperatures were read. After the measurement was completed and the chart paper changed, the chamber was raised and maneuvered to the next plot.

Evapotranspiration in the portable chamber was calculated using equation [3] and compared to solution uptake as shown in Fig. 3. These data were collected on a clear afternoon (28 Aug. 1975) when the plants had reached maximum height. The close association between the absorption rate measured by the solution uptake system and the transpiration rate measured in the portable chamber is evident. Both decrease as radiation decreases at sunset, as shown in the lower section of Fig. 3.

RESULTS AND DISCUSSION

The linear relationship between the transpiration and the solution-absorption rate shown in Fig. 4 indicated that the transpiration rate was measured by the chamber. The small variation ($r^2 = 0.98$) and a slope near unity indicated that the portable chamber did accurately measure the transpiration rate as indicated by the solution uptake rate.

Previous measurements using this technique on a partly cloudy day were considerably more scattered, and indicated that clouds had a significant effect and the absorption was different from the measured transpiration. For example, when radiation changed from low to high, the transpiration rate, measured by the chamber over the solution absorption tank, was larger than the absorption rate, as measured by the solution-uptake system. These data indicated that the plants had a capacity to store water in their tissue and that on a short-term basis, the absorption rate lagged behind the transpiration rate.

We evaluated the combination of the component errors in calculating ET based on the initial and final air and wet-bulb temperatures using the technique described by Doebelin (1966). The error analysis was performed on equation [3] with the time, soil area, and chamber volume, assumed constant. Both air and wet-bulb temperatures were assumed to be read with an accuracy of $\pm$ 0.1 C. After expanding the right-hand side of equation [3] and expressing ET in terms of the four temperatures, ET was differentiated with respect to each temperature and the results yielded an overall error of 19%. If the individual errors are $\pm$ 3 standard deviation limits, then the probable error was 11%. Thus, the error in calculating ET is possibly as large as 19% but probably not larger than 11%. The results suggest that the error involved in calculating ET is reasonable for field measurements as long as the temperatures, especially the wet-bulb temperature, can be read with $\pm$ 0.1 C accuracy. An expanded scale and improved sensitivity of measurements would decrease the probable error.

SUMMARY

The close relationship between the measured transpiration and the solution-uptake rate, as measured by the solution uptake system, verified the accuracy of the measurement on a clear day. Also, the portable chamber method is nondestructive and enables the averaging of many plants in one measurement, as opposed to individual plant measurements. With a portable generator or an inverter ET could be measured in remote field locations. The accuracy and rapidity of the measurement, its portability and relatively low cost makes the chamber useful in evaluating the influence of soil and water management practices on plant water use.

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